Exam in power electronics 2019-06-05 8-13

Means of assistance:	Calculator		
	Grades:	20-30 p:	3
		31-40 p:	4
		41-50 p:	5
In total	5 exercises		

1 The DC-DC buck converter

a) Draw a 2QC 2-level converter connected to the DC side of a three phase diode rectifier, which is connected to the power grid. The DC link capacitor and protection against too high inrush currents should be included in the drawing. The transistor is of IGBT-type. (1 p.)

b) The three-phase grid, to which the three phase diode rectifier is connected, has the line-to-line voltage 380 V_{RMS} and the frequency 50 Hz. Calculate the DC output voltage and the maximum DC link voltage from the rectifier. (1 p.)

c) Calculate the rms-current and the average current through one rectifying diode (see figure 1, assume half-sinusoid shape). Calculate the rectifier diode losses. The diode threshold voltage is 1.0 V and the differential resistance is 1.8 mOhm. (2 p.)

d) Calculate the IGBT component losses of each IGBT in the 2QC.
Draw a time diagram with the converter phase current versus time during one period of the switching frequency. (4 p.)

- The 2Q converter output inductor is 0.7 mH, and its resistance can be neglected.
- The load on the low voltage side of the 2Q converter is a battery with the voltage 400 V_{DC}.
- The switching frequency is 2 kHz.
- The threshold voltage of the IGBT transistor equals 1.0 V and its differential resistance equals 1.4 mOhm.
- The turn-on loss of the IGBT transistors equals 45 mJ and their turn-off loss equals 72 mJ. These turn-on and turn-off losses are nominal values at 900 V DC link voltage and 180 A turn-on and turn-off current.
- The threshold voltage of the freewheeling diode equals 1 V and the differential resistance of this diode equals 2 mOhm. The freewheeling diodes turn-on losses can be neglected and their turn-off losses equals 30 mJ, at 900 V DC link voltage and 180 A turn off current.

e) Which is the junction temperature of the IGBT transistor and of the freewheeling diode, and which is the junction temperature of the rectifying diodes?

- The thermal resistance of the heatsink equals 0.065 K/W?
- The thermal resistance of the IGBT transistor equals 0.08 K/W?
- The thermal resistance of the freewheeling diode equals 0.2 K/W?
- The thermal resistance of the rectifier diode equals 0.25 K/W?
- The ambient temperature is 35 ºC.
- The rectifier diodes and the buck converter transistor and diode share the heatsink. (2 p.)

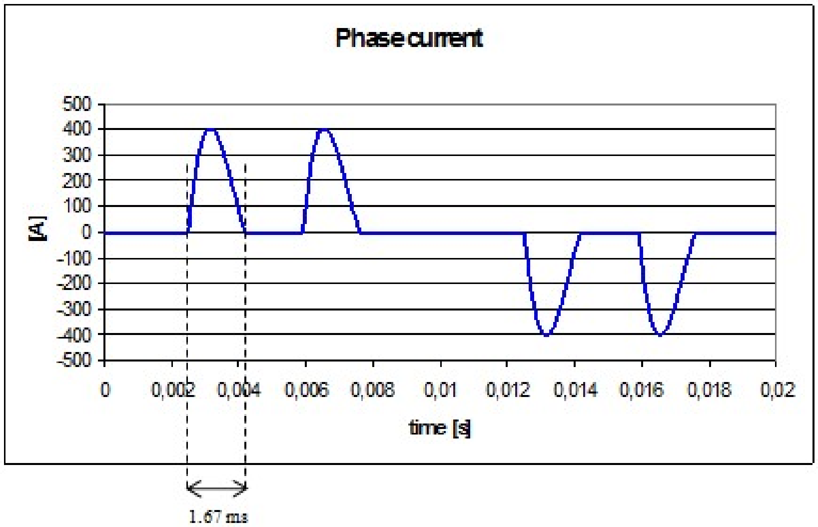

Figure 1

2 Snubbers and converters

a) Draw an IGBT equipped step down chopper (buck converter) with an RCD snubber. Give a detailed description of how the RCD charge-discharge snubber operates at turn on and at turn-off. Explain why the snubbers are needed (2 p.)

b) Calculate the snubber capacitor for the commutation time 0.01ms.

Calculate the snubber resistor so the discharge time (3 time constants) of the snubber capacitor is less than the IGBT on state time. (3 p.)

- The load current is 15 A, assumed constant during the commutation.
- The DC link voltage on the supply side is 250V and the load voltage is 150 V.
- The switch frequency is 2 kHz

c) Draw the circuit of a DC supplied 3-level output NPC (neutral point clamping) converter. The answer shall also contain a table with the status (which are on and which are off) of the switches at the three different output voltage levels. (3 p.)

d) Draw the circuit of a Fly-Back DC/DC converter. The drawing shall contain snubbers at three different positions in the circuit, An explanation is required what the snubbers are protecting from at the three positions. (2 p.)

3 Three Phase

a) A symmetric three phase voltage:

$$\begin{cases} e_a = \hat{e} \cdot \cos(\omega \cdot t) \\ e_b = \hat{e} \cdot \cos\left(\omega \cdot t - \frac{2\pi}{3}\right) \\ e_c = \hat{e} \cdot \cos\left(\omega \cdot t - \frac{4\pi}{3}\right) \end{cases}$$

Show that these voltages form a rotating vector with constant length and constant speed in the complex (α,β) frame. (5 p.)

b) Draw the circuit of a current control block for a generic three phase RLE load. The drawing shall include three phase converter, reference and load current measurement. It must be clear in which blocks the different frame transformations occur. (5 p.)

4 Current control

A 4-quadrant DC converter is used for current control in a speed control loop with a DC motor. The following parameters are describes the drive.

```
>> La=0.001; % DC motor armature inductance
>> Ra=0; % DC motor armature resistance
>> Udc=600; % DC link voltage
>> Ts = ?? % Sampling time
>> ψm = 1.2; % DC motor magnetizing flux linkage
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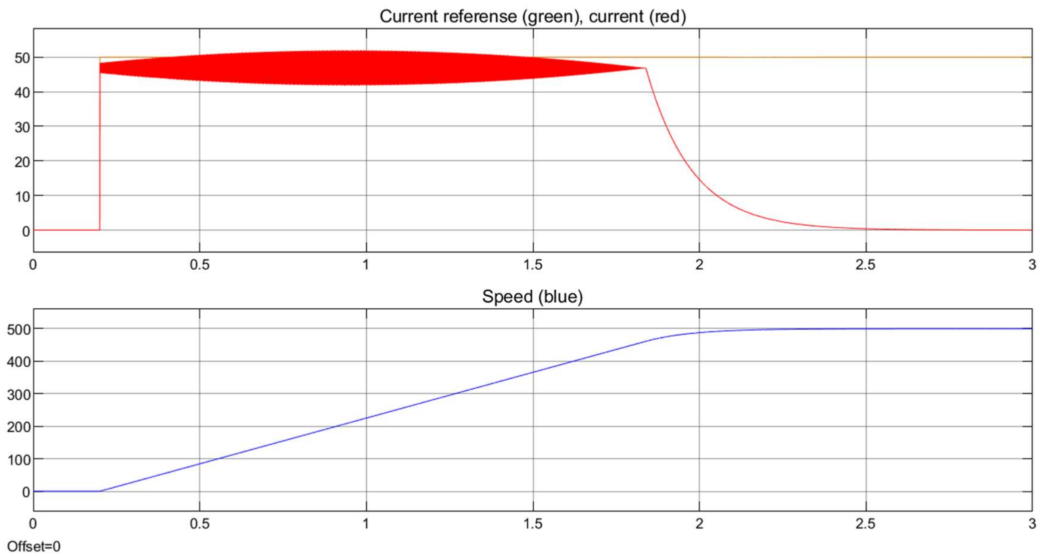
a) Assume that carrier wave modulation of a 4Q converter is used. What carrier wave frequency is required to have a maximum current ripple of 10 Ampére. What is then the sampling time?? (4p)

Di/dt=(Udc-e)/La; Delta_i = tp(Udc-e)/La. Max ripple at e=ω*Psim=Udc/2, i.e Delta_i = 1/4/fm*(Udc-e)/La -> fm=1/4/Delta_i*(Udc-e)/La = 1/4/10*300/0.001=7500; Ts=1/2/fm=0.000067 s.*

b) Design a PI current controller for the 4Q converter driving the motor. Assume that acceleration starts with a 0 to 50 Ampére current step <u>from a standstill rotor</u>. Is one sampling interval enough for the current control to eliminate the initial current error, given your assumption of carrier wave frequency from the previous question? If not - how many sampling periods are needed? Assume that there is a current limit at +/- 50 A, and that ψ_m=1. (4p)

*La/Ts = 0.001/0.000067*100 = 1500 V, i.e. three periods are needed*

c) In the figure below, a current step response is illustrated with a rotor current limit of 20 A, and the drive is allowed to accelerate freely. Why is the current ripple biggest in the middle of the acceleration and why is the current control lost in the end of the acceleration? (2p)



*e=Udc/2, e>Udc-Ra*i*

5 Electrical machines

A permanently magnetized synchronous machine is used as a traction motor.

a) Which is the fundamental electric stator voltage frequency of a PM machine running at 20000 rpm if it has 10 poles? (2p)

*F=15000/60*8/2=1000 Hz*

b) Which is the highest phase to phase voltage [RMS] that a 2-level inverter can supply if the DC link is 600 V and symmetric carrier wave modulation is used? (2p)

Upp = 600/sqrt(2) = 424 [V, RMS]

c) What is the mechanical base speed of a drive with data according to a) and b) if the flux linkage at the limit of base speed and nominal torque <u>in one phase is</u> 0.185 [Vs, <u>RMS</u>]? (3p)

*Wel,base = 424/(0.125*sqrt(3)) = 1323 rad/s*

*Nmech,base = Wel,base/(2pi)*2/10*60 = 2527 rpm*

d) An induction machine is vector controlled. What is the main difference between a vector control system of a PM synchronous machine and an induction machine (3p)

The flux position of the induction machine must be estimated based on the stator voltages, stator currents and possibly the rotor speed. In the synchronous machine the rotor position is enough to measure.